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# SEMIDIURNAL BOTTOM PRESSURE AND TIDAL CURRENTS ON GEORGES BANK AND IN THE MID-ATLANTIC BIGHT

by

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This report is preliminary and has not been edited or reviewed
for conformity with U.S. Geological Survey standards or nomenclature.

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# SEMIDIURNAL BOTTOM PRESSURE AND TIDAL CURRENTS ON GEORGES BANK AND IN THE MID-ATLANTIC BIGHT

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## ABSTRACT

Observations of the semidiurnal ($M_2$) tidal current, bottom pressure, and coastal sea level from Nova Scotia to Cape May, New Jersey, show that: 1) the surface pressure at the edge of the Continental Shelf in the study area has a relatively uniform amplitude (40 cm) and phase (12 hr Greenwich); 2) in the Mid-Atlantic Bight the semidiurnal $M_2$ tide is co-oscillating, and the onshore $M_2$ tidal current reaches a maximum approximately $90^o$ or 3.1 hr before high water; 3) in the Georges Bank region of the shelf, the $M_2$ tide is more progressive than it is in the Mid-Atlantic Bight, and the onshore $M_2$ tidal current in the Georges Bank region of the shelf reaches a maximum about $7^o$ or 14 min before high water; 4) the strongest $M_2$ tidal currents observed in the study area are near the crest of Georges Bank (typical amplitudes are 74 cm/s near the surface); 5) the $M_2$ tidal currents are weaker in the Mid-Atlantic Bight (typical amplitudes are 16 cm/s near the surface) than on Georges Bank; and 6) the tidal currents are weakest near the bottom south of Cape Cod in a region of transition between progressive and co-oscillating tides.

## INTRODUCTION

One of the major features of the Georges Bank region of the Continental Shelf is the strong rotary semidiurnal tidal currents. The tidal signal dominates all current and pressure measurements and is stronger on Georges Bank than along the Mid-Atlantic Bight. The strong tides may cause several of the physical, geological, and biological features unique to Georges Bank. Loder (1980) suggests that the

residual clockwise circulation around Georges Bank may be caused by a nonlinear interaction between the semidiurnal tidal currents and the bank topography. The strong tides also influence the water stratification and vertical mixing. On the crest of the bank and over Nantucket Shoals, the water is vertically well mixed throughout the year; this mixing results in a tidally induced front at the 50-to 60-m isobath in summer. Garrett and others (1978) have applied the mixing models of Simpson and Hunter (1974) and, using tidal velocities from a numerical model, have successfully predicted the location of these tidally mixed fronts. The strong tidal mixing may partially cause the high biological productivity on Georges Bank. Noble and Butman (1979) have used coastal sea-level data to suggest that the strong tidal currents effectively increase the bottom stress for a unit longshelf current and may result in reduced low-frequency wind-induced, longshelf currents in this region. Recent current observations (Noble and Butman, 1979) show smaller low-frequency currents on Georges Bank than in the Mid-Atlantic Bight. Because the strong tidal currents dominate the average bottom stress, they play a major role in determining the present distribution of surface sediments and the fate of material introduced into the water. Finally, the strong tides probably cause the existing sand waves and sand ridges on the crest of the bank, in Great South Channel, and on Nantucket Shoals.

Previous studies of the semidiurnal tide along the east coast of North America (Redfield, 1953, 1958; Beardsley and others, 1977; Greenberg, 1979; Vermersch and others, 1979) have addressed the surface pressure field. This paper summarizes these previous observations of the $M_2$ tidal elevation and presents our recent bottom-pressure and current observations made from 1975 to 1979 along the U.S. east coast Continental Shelf.

## DATA

We have analyzed current and bottom-pressure records collected on Georges Bank and in the Mid-Atlantic Bight for the $M_2$ tide (period 12.42 hr). Bottom pressure and currents were measured by instruments on a bottom tripod (Butman and Folger, 1979). We estimate the direction error in the near-bottom current measurements to be $\pm 5^{\circ}$. The near-surface and mid-depth current measurements were made by using AMF[1] vector-averaging current meters on taut subsurface or slack surface moorings. We estimate instrument direction errors for these instruments to be approximately $\pm 1.4^{\circ}$. Time errors for both instrument systems are $\pm 1$ s/d.

The data series were divided into 29-day pieces, and tidal estimates for each 29-day piece were computed by a modified version of the National Ocean Survey harmonic method (Dennis and Long, 1971). Twenty-nine day pieces were used to maximize data length and allow some computation of variability. The Fourier coefficients (amplitude and phase for east and north current and bottom pressure) and the current ellipse representation are tabulated in table 1 for Georges Bank and in table 2 for the Mid-Atlantic Bight. The amplitude was computed as the average of the estimates from each 29-day data segment. The phase and orientation estimates are vector averages of the angular estimates. The angle estimates were generally very steady. The vector-averaged orientation and phase were usually within $1^{\circ}$ of the arithmetic average. The standard deviations from the arithmetic means of the tidal amplitudes and phases are included (where enough 29-day pieces were

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[1]Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

available) to indicate approximate confidence level.

We have also assembled additional published $M_2$ tidal observations. The locations of all stations except T21, T1, Eastport, Maine, and Bermuda are shown in figure 1 and the elevation data are tabulated in table 3 using station notations as reported in the literature.

The tidal data are presented graphically in two forms. Current ellipses for Georges Bank and the Mid-Atlantic Bight are shown in figures 2a and b (note the scale change). In figures 3a through d the spatial patterns of currents and the surface elevation of the water (calculated from subsurface pressure) are shown for 0, 3, 6, and 9 hours after moon's passage over Greenwich.

## RESULTS

The $M_2$ tidal currents on Georges Bank and in the Mid-Atlantic Bight are rotary and sweep out the tidal ellipse every tidal cycle (figs. 2a and b). At most stations, the major axis of the semidiurnal tidal ellipse was approximately perpendicular to the local isobaths. In the Great South Channel (stations B, M), the major axis was parallel to the channel axis, and in the transition zone between Georges Bank and Mid-Atlantic Bight (stations P, I), the major axis was parallel to the local isobaths. The near-surface (15-m) tidal currents were strongest on the crest of Georges Bank (station C, major axis 74 cm/s) and in Great South Channel (station M, 73 cm/s) and were weakest west of Nantucket Shoals (stations I, P). The maximum velocities of tidal currents on the north (station D) and south (stations A, K) flanks of Georges Bank were about 39 cm/s. At the edge of the Continental Shelf in the Mid-Atlantic Bight (station MB) the maximum velocity of the near-surface current was only 16 cm/s. Velocities of tidal currents measured 1 m above the bottom on Georges Bank varied between 22 cm/s (station A) and 32 cm/s (station K) and were about 7 cm/s in the Mid-Atlantic Bight. The weakest near-bottom semidiurnal tidal currents were observed south of Cape Cod (station P, 6 cm/s). The tidal ellipse was most circular at station P and most elongated in Great South Channel (stations B and M).

The semidiurnal tidal currents changed slightly with depth, primarily in the bottom frictional Ekman layer. For example, at station A (fig. 2a) on the southern side of Georges Bank: 1) the amplitude of the major axis of the tidal ellipse decreased 11% between 15 m and 75 m and 33% between 75 m and 84 m; 2) the phase or time of maximum velocity was earliest near the bottom--the near-bottom tidal current (84 m) led the mid-depth tidal current (45 m) by $14^{\circ}$ or 28 min;

and 3) the ellipse orientation rotated $10^{o}$ clockwise between 45 and 84 m.

Our observations show that the nature of the semidiurnal tidal wave in the Mid-Atlantic Bight was different from that in the Georges Bank region. Along the 100-m isobath from New Jersey to Nova Scotia, the phase of the semidiurnal tide was approximately constant (12 hr Greenwich), and the amplitude of the surface tide (determined from subsurface pressure) was about 40 cm. In the Mid-Atlantic Bight, the tidal amplitude increased to 55-60 cm at the coast, the phase of the semidiurnal tide varied only $4^{o}$ ($347^{o}$-$351^{o}$) across the shelf, and maximum onshore flow led high water by approximately $90^{o}$ (3.1 hr). The co-oscillating nature of the $M_2$ tide (fig. 3) in this region was similar to that described by Redfield (1958) for mean high water. In the Georges Bank region of the shelf, the tidal wave was more progressive. Across Georges Bank, the tidal amplitude increased from 38.9 cm (station A) to 75.8 cm (station D), and the phase varied $88^{o}$ ($5^{o}$-$93^{o}$). On the southern flank (station A), the average onshore flow reached a maximum about $7^{o}$ (14 min) before surface pressure reached a maximum. The currents in the Mid-Atlantic Bight led the currents on Georges Bank by 3-4 hr because of the different natures of the tides in the two areas; onshore tidal flow along the Mid-Atlantic Bight took place during southwesterly flow on Georges Bank.

## ACKNOWLEDGEMENTS

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## REFERENCES CITED


Beardsley, R. C., Moffeld, H., Wimbush, M. A., Flagg, C. N., and Vermersch, J. A., 1977, Ocean tides and weather-induced bottom pressure fluctuations in the Middle Atlantic Bight: Journal of Geophysical Research, v. 82, no. 21, p. 3175-3182.

Butman, B., and Folger, D. W., 1979, An instrument system for long-term sediment transport studies on the Continental Shelf: Journal of Geophysical Research, v. 84, p. 1215-1220.

Dennis, R. E., and Long, E. E., 1971, A users guide to a computer program for harmonic analysis of data at tidal frequencies: U.S. National Oceanic and Atmospheric Administration (NOAA) Technical report NOS41, p. 29.

Garrett, C. J. R., Keeley, J. R., and Greenberg, D. A., 1978, Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine: Atmosphere-Ocean, v. 16, no. 4, p. 403-423.

Garrett, C., and Toulany, B., 1979, A variable depth Green's function for the shelf edge: Journal of Physical Oceanography, v. 9, no. 6, p. 1258-1272.

Greenberg, D. A., 1979, A numerical model investigation of tidal phenomena in the Bay of Fundy and Gulf of Maine: Marine Geodesy, v. 2, p. 161-187.

Loder, J. W., 1980, Topographic rectification of tidal currents on the sides of Georges Bank: Journal of Physical Oceanography, v. 10, p. 1399-1416.

Noble, M., and Butman, B., 1979, Low-frequency wind-induced sea-level oscillations along the east coast of North America: Journal of Geophysical Research, v. 84, no. 6, p. 3227-3236.

Redfield, A. C., 1953, Interference phenomena in the tides of the Woods Hole region: Journal of Marine Research, v. 12, p. 121-140.

Redfield, A. C., 1958, The influence of the Continental Shelf on the tides of the Atlantic Coast of the United States: Journal of Marine Research, v. 17, p. 432-448.

Simpson, J. H., and Hunter, J. R., 1974, Fronts in the Irish Sea: Nature, v. 250, p. 404-406.

Vermersch, J. A., Beardsley, R. C., and Brown, W. S., 1979, Winter circulation in the western Gulf of Maine, Part II: current and pressure observations: Journal of Physical Oceanography, v. 9, no. 4, p. 768-784.

White, R. E., and White, M. J., 1979, Eldridge Tide and Pilot Book: Boston, Robert Eldridge White, 264 p.

Zetler, B., Munk, W., Moffeld, H., Brown, W., and Dormer, F., 1975, Mode tides: Journal of Physical Oceanography, v. 5, no. 3, p. 430-431.

Figure 1. Locations of stations (table 3) along part of the Atlantic coast of North America where semidiurnal tidal data were collected. Locations of three stations (T21, T1, and Eastport, Maine) used to contour the surface elevation (fig. 3) are not shown in this figure.

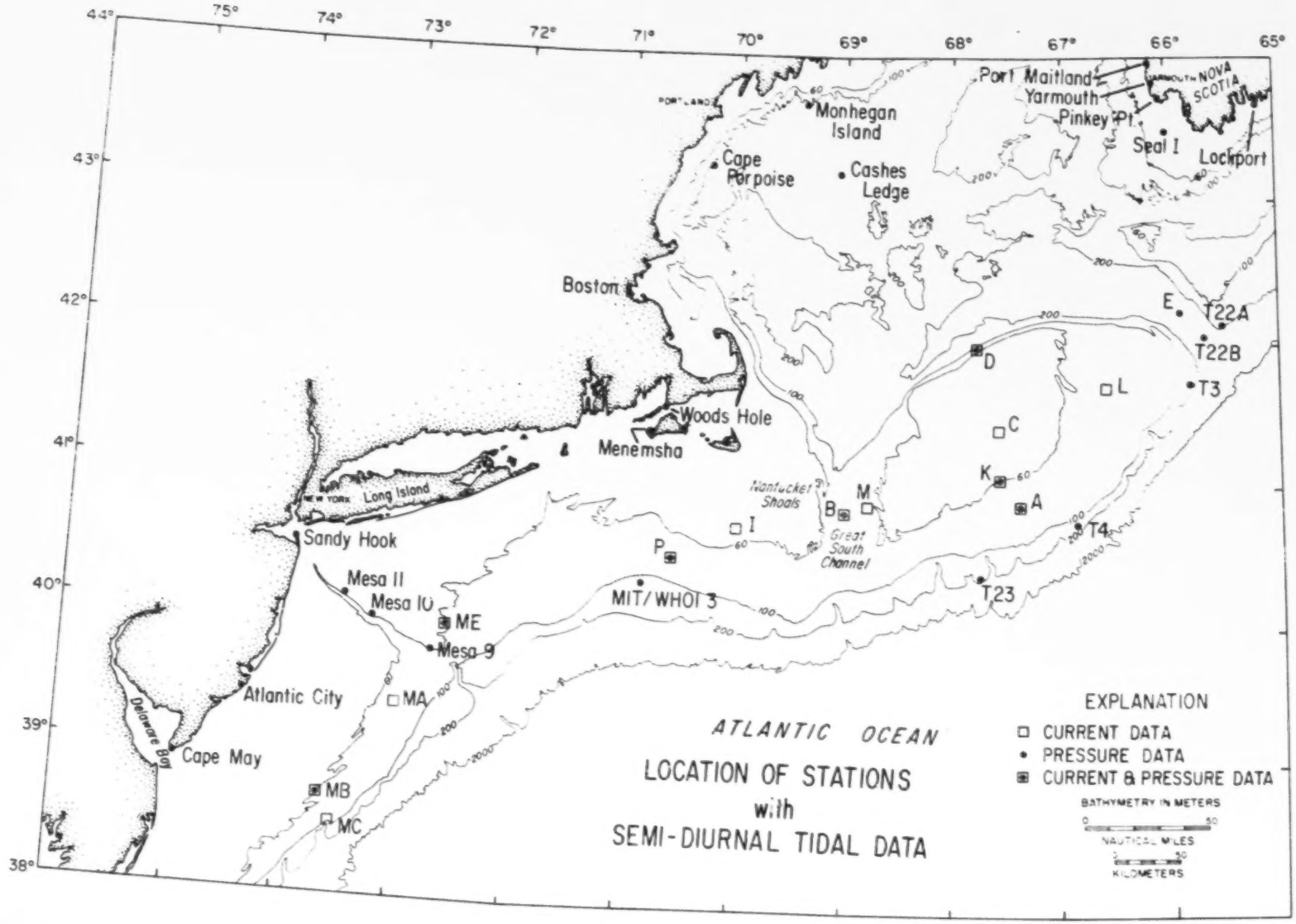
44°
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
43°
42°
41°
40°
39°
38°
Port Maitland
Yarmouth
Pinkey Pt.
NOVA SCOTIA
Seal I
Lockport
Monhegan Island
Cape Porpoise
Cashes Ledge
Boston
E
T22A
T22B
D
L
T3
C
Woods Hole
Menemsha
K
A
M
B
I
P
Nantucket Shoals
Great South Channel
T4
T23
Sandy Hook
Long Island
NEW YORK
Mesa II
Mesa 10
ME
Mesa 9
MIT/WHOI 3
Atlantic City
MA
Delaware Bay
Cape May
MB
MC
ATLANTIC OCEAN
LOCATION OF STATIONS
with
SEMI-DIURNAL TIDAL DATA
EXPLANATION
CURRENT DATA
PRESSURE DATA
CURRENT & PRESSURE DATA
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS

Figure 1

Figure 2a-b. Georges Bank and Mid-Atlantic Bight $M_2$ tidal ellipses. The times indicated on the outside of the ellipse are Greenwich mean time. The depth of the tidal ellipse below the surface is shown on the ellipse circumference, and the water depth is shown in parentheses below the station identification letter in the center of the ellipse. The ellipses are arranged in approximate relative geographical positions. In order that these ellipses can be used with local tide tables, the approximate time of Boston high water is indicated by the solid circle on the ellipse. The solid circle corresponds to the phase of the $M_2$ surface tide at Boston (table 3).

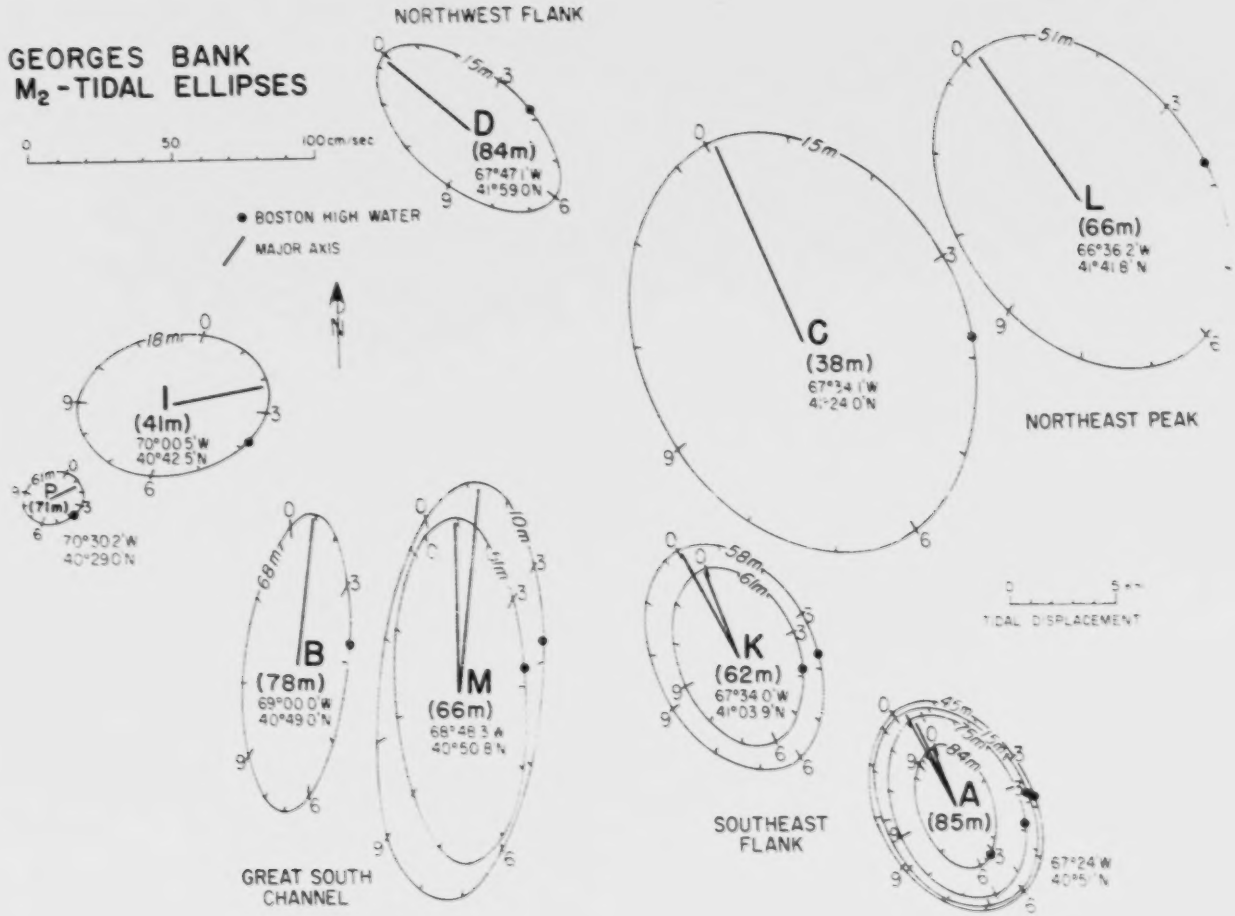
GEORGES BANK
$M_2$ - TIDAL ELLIPSES
0 50 100 cm/sec
BOSTON HIGH WATER
MAJOR AXIS
N
NORTHWEST FLANK
D
(84m)
67°47.1'W
41°59.0'N
I
(41m)
70°00.5'W
40°42.5'N
P
(71m)
70°30.2'W
40°29.0'N
B
(78m)
69°00.0'W
40°49.0'N
M
(66m)
68°48.3'W
40°50.8'N
GREAT SOUTH CHANNEL
C
(38m)
67°34.1'W
41°24.0'N
L
(66m)
66°36.2'W
41°41.8'N
NORTHEAST PEAK
TIDAL DISPLACEMENT
K
(62m)
67°34.0'W
41°03.9'N
SOUTHEAST FLANK
A
(85m)
67°24.W
40°5.'N

Figure 2a

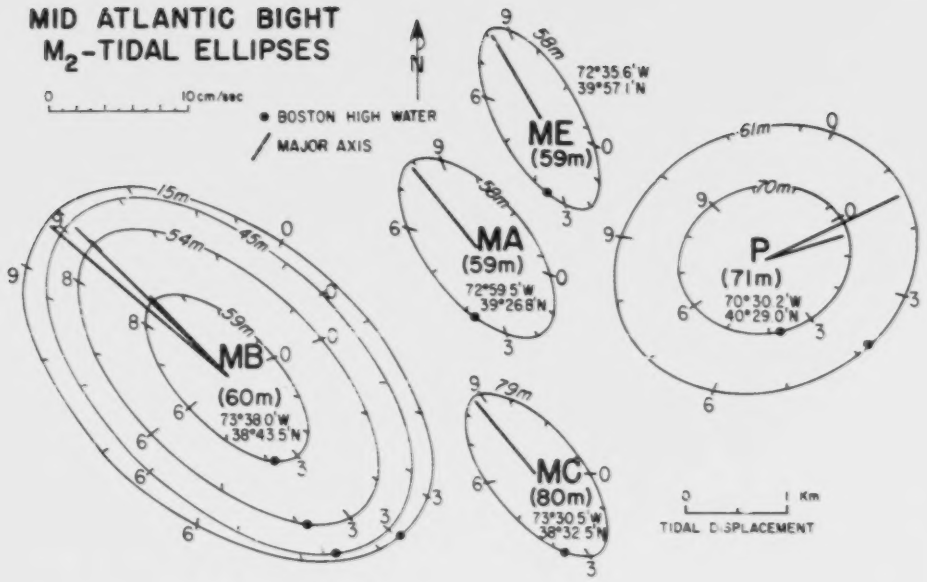
MID ATLANTIC BIGHT
$M_2$-TIDAL ELLIPSES
0 10cm/sec
N
BOSTON HIGH WATER
MAJOR AXIS
ME
(59m)
72°35.6'W
39°57.1'N
MA
(59m)
72°59.5'W
39°26.8'N
MB
(60m)
73°38.0'W
38°43.5'N
MC
(80m)
73°30.5'W
38°32.5'N
P
(71m)
70°30.2'W
40°29.0'N
15m
45m
54m
59m
61m
70m
79m
0 1 Km
TIDAL DISPLACEMENT

Figure 2b

Figure 3a-d. Currents and water surface elevation in the Mid-Atlantic Bight and on Georges Bank for 0, 3, 6, and 9 hours after moon's passage over Greenwich. The current vectors are drawn from a vertically "eye-averaged" ellipse based on figures 2a and b. Because the near-bottom ellipses at stations MA, MC, and ME were similar to that at station MB, the "average ellipse" of station MB was used at all four stations. The coastal currents (open arrows) were taken from "Eldridge Tide and Pilot Book" (White and White, 1979) and are shown at a different scale than the shelf currents. The surface elevation of $M_2$ tide is in cm and the $M_2$ amplitude near Bermuda (deep ocean) is shown near the bottom of each figure. The dotted line connects stations where high water or low water occurs at the same time. The dotted line at the edge of the Continental Shelf corresponds to a progressive crest or trough of water but does not correspond to a crest or trough in the Gulf of Maine where the surface motion is more complex due to the Bay of Fundy.

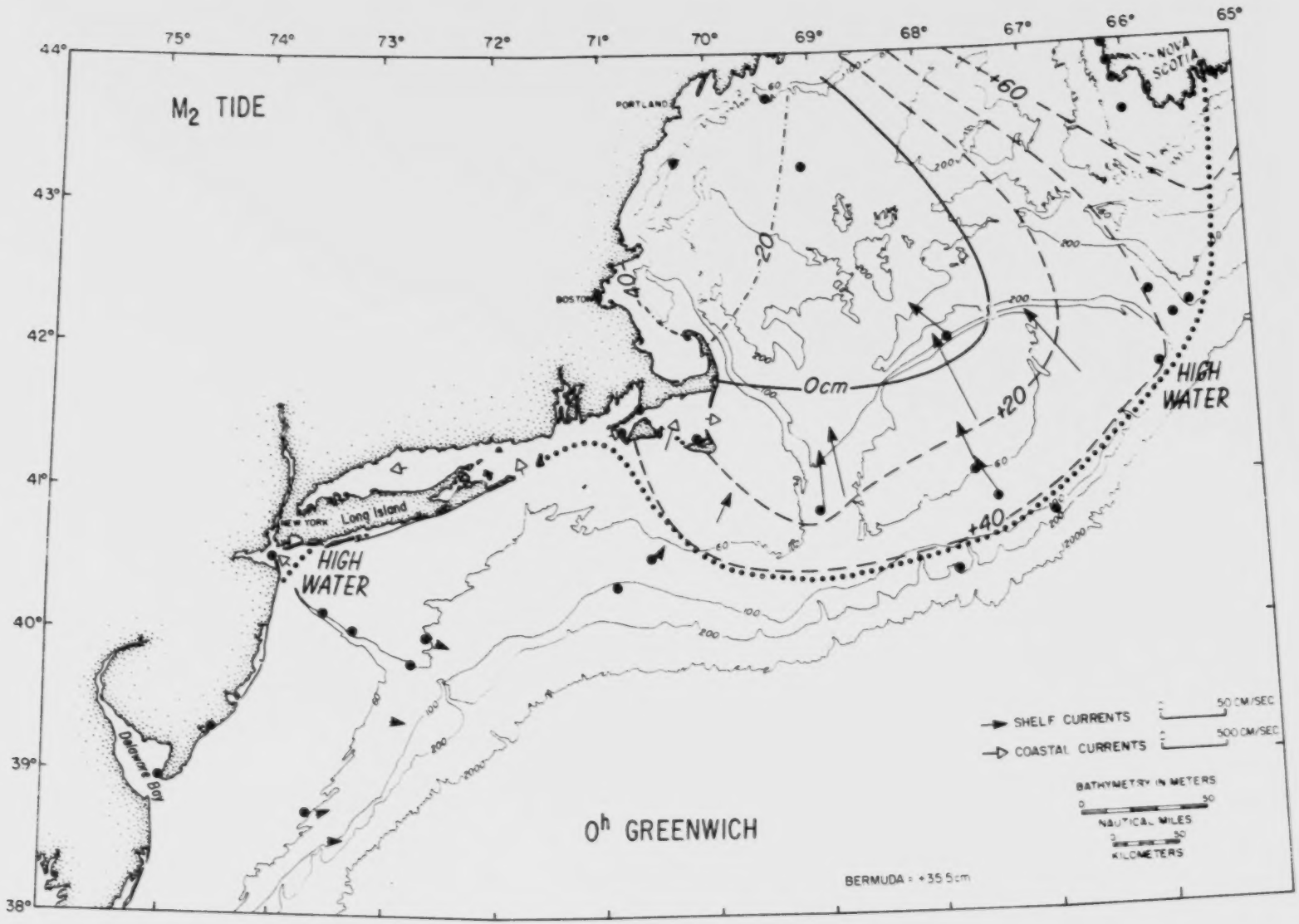
M2 TIDE
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
44°
43°
42°
41°
40°
39°
38°
PORTLAND
BOSTON
NEW YORK
Long Island
Delaware Bay
NOVA SCOTIA
+60
+40
+20
0cm
HIGH WATER
HIGH WATER
SHELF CURRENTS
50 CM/SEC
COASTAL CURRENTS
500 CM/SEC
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
0h GREENWICH
BERMUDA = +35.5cm

Figure 3a

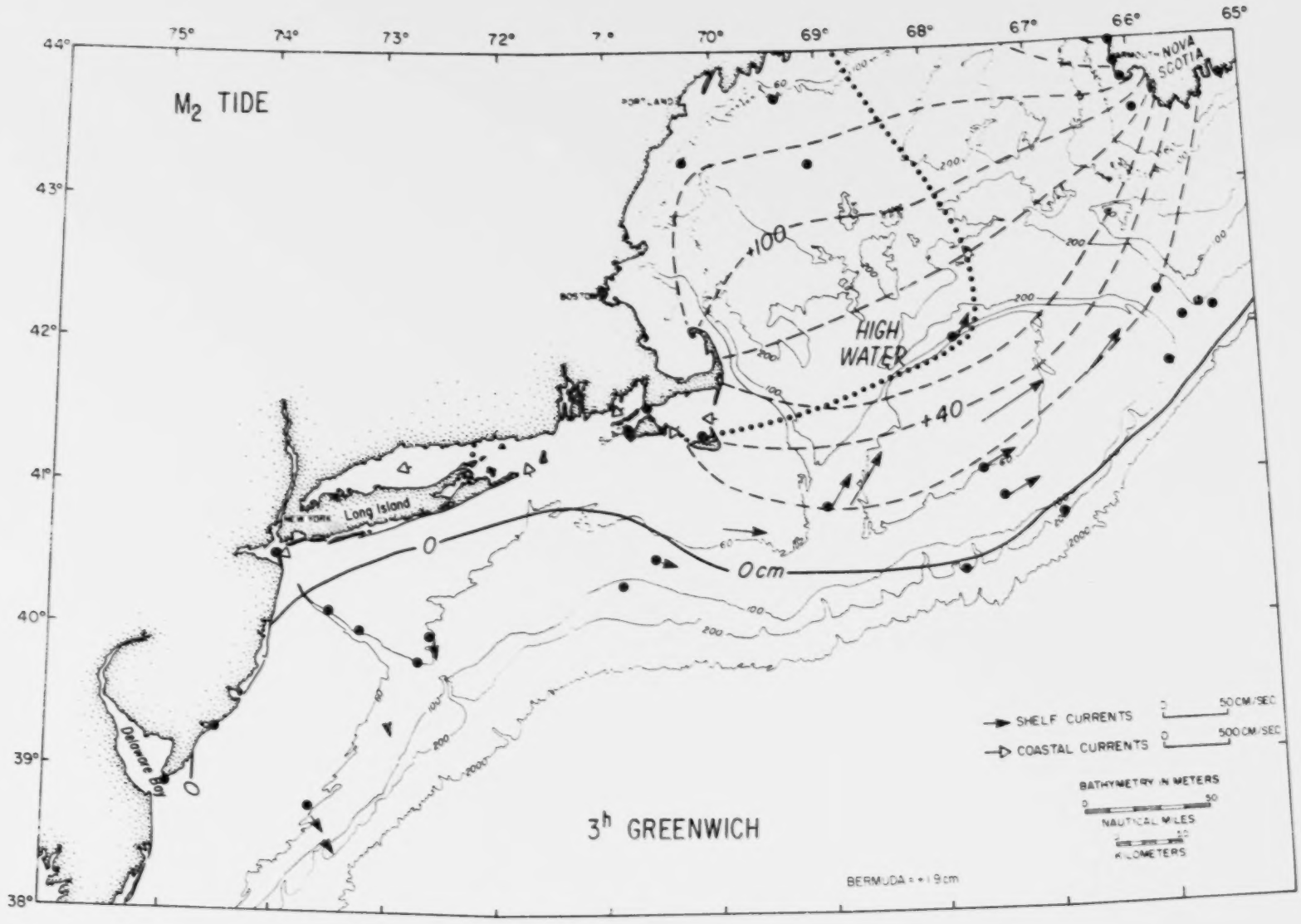
M2 TIDE
HIGH WATER
+100
+40
0
0cm
Long Island
Delaware Bay
NOVA SCOTIA
SHELF CURRENTS
COASTAL CURRENTS
50 CM/SEC
500 CM/SEC
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
3h GREENWICH
BERMUDA = +19cm
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
44°
43°
42°
41°
40°
39°
38°

Figure 3b

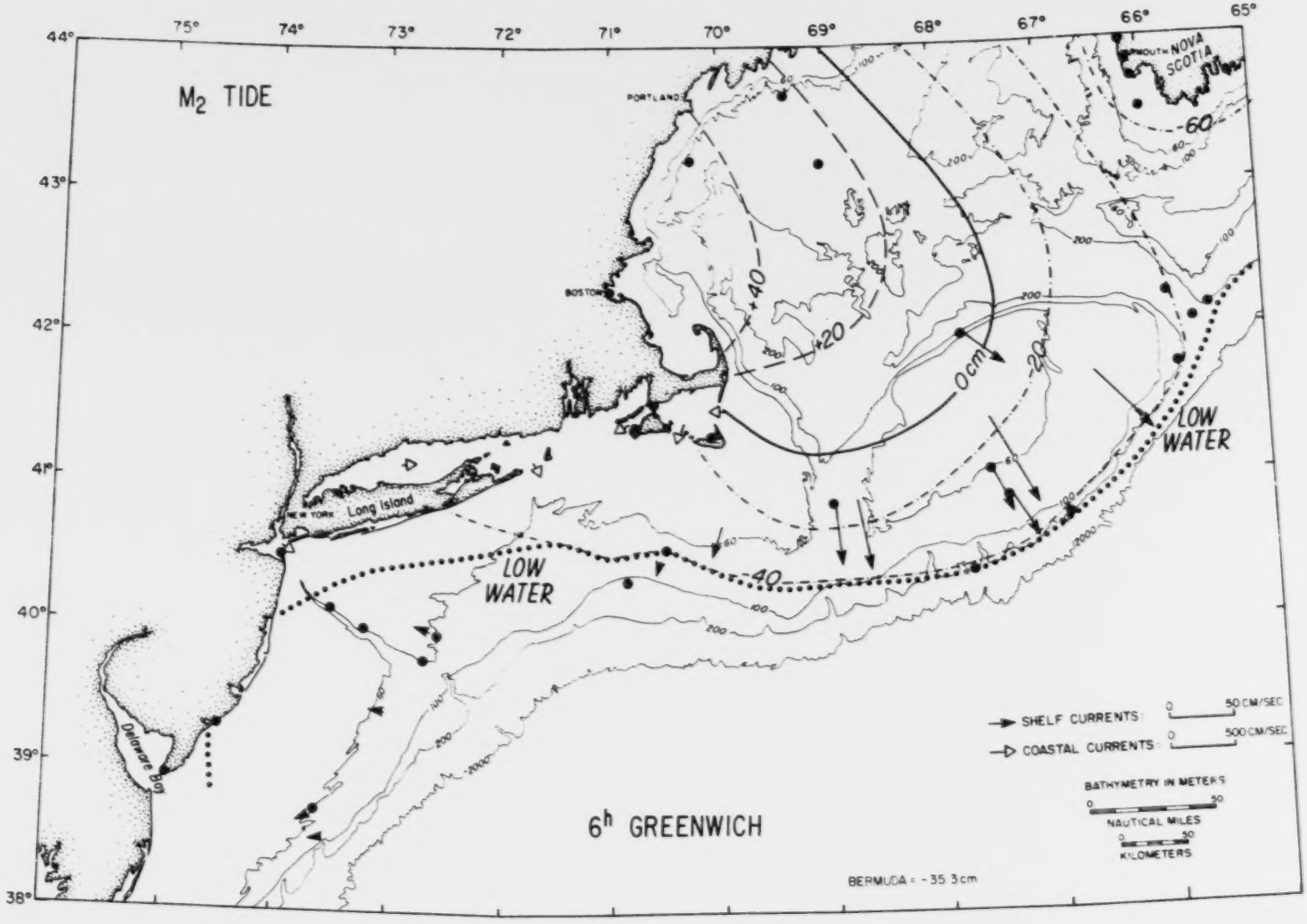
M2 TIDE
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
44°
43°
42°
41°
40°
39°
38°
PORTLAND
BOSTON
NEW YORK
Long Island
Delaware Bay
SOUTH NOVA SCOTIA
-60
-40
+20
0cm
20
40
60
100
200
2000
LOW WATER
LOW WATER
SHELF CURRENTS: 0 50 CM/SEC
COASTAL CURRENTS: 0 500 CM/SEC
BATHYMETRY IN METERS
0 50
NAUTICAL MILES
0 50
KILOMETERS
6h GREENWICH
BERMUDA = -35.3cm

Figure 3c

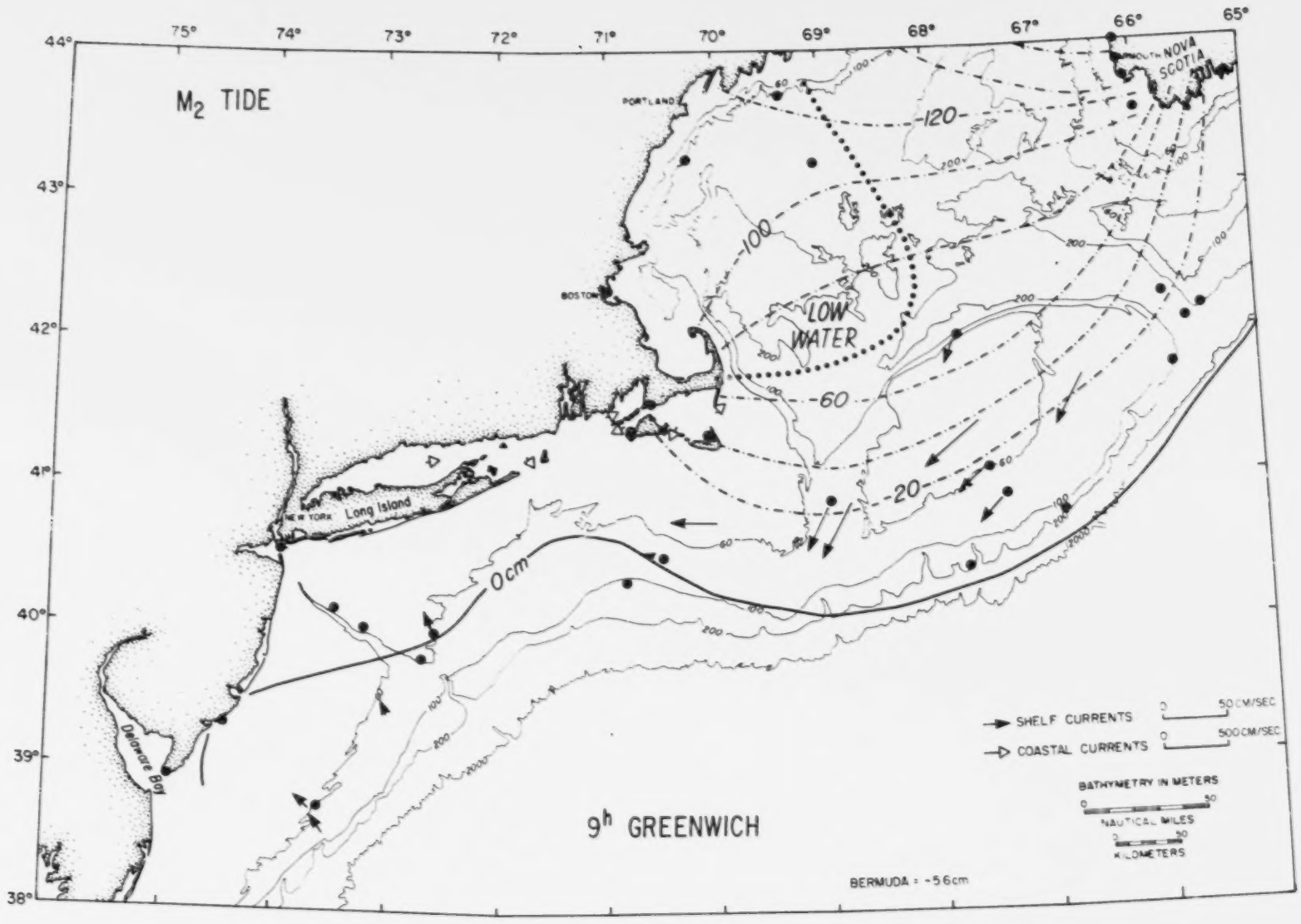
M2 TIDE
LOW WATER
120
100
60
20
0cm
Long Island
Delaware Bay
PORTLAND
BOSTON
NEW YORK
SOUTH NOVA SCOTIA
SHELF CURRENTS
COASTAL CURRENTS
50 CM/SEC
500 CM/SEC
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
9h GREENWICH
BERMUDA : -56cm
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
44°
43°
42°
41°
40°
39°
38°

Figure 3d

## TABLE I - SEMIDIURNAL ($M_2$) TIDAL PARAMETERS FOR GEORGES BANK

| Station or long fig 1 | No of 29-day pieces | Meters below surface (m) | Mean water depth (m) | FOURIER COEFFICIENTS: PRESSURE Amp (mbar) | PRESSURE Phase-G (deg) | PRESSURE BHW[1] (hrs) | CURRENTS East Amp (cm/s) | CURRENTS East Phase-G (deg) | CURRENTS North Amp (cm/s) | CURRENTS North Phase-G (deg) | CURRENT ELLIPSE PARAMETERS: Umaj (cm/s) | Umin (cm/s) | Umin/Umaj | e* | Orient North=0° (deg) | Phase-G (deg) | BHW[1] (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A 40°51'N 67°24'W | 9 | 15 | 85 | — | — | — | 27.5±1.7 | 137.0±4.0 | 34.2±2.6 | 027.3±2.5 | 36.6±2.4 | -24.2±1.9 | 0.66 | 0.75 | 331.5±2.8 | 007.6±1.7 | 3.5 |
| | 33 | 45 | 85 | — | — | — | 29.4±1.8 | 134.5±4.0 | 35.8±1.4 | 025.9±3.5 | 38.3±1.6 | -26.0±1.6 | 0.68 | 0.73 | 330.9±3.1 | 002.1±5.1 | 3.7 |
| | 33 | 75 | 85 | — | — | — | 22.9±1.5 | 119.2±4.5 | 30.6±1.9 | 008.3±5.3 | 32.5±2.0 | -20.1±1.3 | 0.62 | 0.79 | 334.9±2.4 | 352.1±2.9 | 4.1 |
| | 0 | 84 | 85 | — | — | — | 14.1±1.4 | 108.2±9.9 | 21.0±1.2 | 000.0±5.9 | 21.8±1.5 | -12.9±0.9 | 0.59 | 0.81 | 341.3±5.6 | 348.6±3.4 | 4.2 |
| | 14 | 84 | 85 | 39.1±0.3 | 004.5±1.1 | 3.6 | — | — | — | — | — | — | — | — | — | — | — |
| B 40°49'N 69°00'W | 3 | 58 | 78 | — | — | — | 18.0±1.1 | 097.2±9.2 | 57.7±1.2 | 025.8±0.5 | 58.0±1.0 | -16.9±1.9 | 0.29 | 0.96 | 006.1±2.6 | 027.5±0.7 | 2.9 |
| | 4 | 77 | 78 | 26±0 | 046.7±1.6 | 2.2 | — | — | — | — | — | — | — | — | — | — | — |
| C 41°24'N 67°34'W | 4 | 15 | 38 | — | — | — | 59.0±6.7 | 122.4±0.7 | 71.6±2.2 | 020.2±0.8 | 74.3±3.7 | -55.6±5.1 | 0.75 | 0.66 | 336.4±0.8 | 002.2±0.8 | 3.7 |
| D 41°59'N 67°47'W | 4 | 15 | 84 | — | — | — | 29.6±2.3 | 158.9±19.7 | 28.1±7.9 | 034.3±26.6 | 36.7±6.3 | -18.3±2.7 | 0.50 | 0.87 | 310.2±13.4 | 002.6±11.4 | 3.7 |
| | 1 | 83 | 84 | 76.2- | 093.4- | 0.6 | — | — | — | — | — | — | — | — | — | — | — |
| E 42°4'N 65°51'W | 5 | 210 | 215 | 45±0.4 | 024.2±1.6 | 3.0 | — | — | — | — | — | — | — | — | — | — | — |
| I 40°43'N 70°01'W | 1 | 18 | 41 | — | — | — | 34.0- | 071.0- | 24.6- | 347.4- | 34.2- | -24.3- | 0.71 | 0.70 | 080.7- | 064.3- | 1.6 |
| K 41°04'N 67°34'W | 3 | 58 | 62 | — | — | — | 30.3±0.7 | 129.0±0.7 | 38.7±1.1 | 019.4±0.5 | 41.2±1.1 | -26.8±0.6 | 0.65 | 0.76 | 333.2±0.7 | 001.2±0.9 | 3.8 |
| | 8 | 61 | 62 | — | — | — | 22.1±1.3 | 115.5±5.6 | 30.4±0.9 | 008.1±3.3 | 31.8±1.0 | -20.2±1.1 | 0.64 | 0.77 | 339.0±5.4 | 354.4±3.2 | 4.0 |
| | 12 | 61 | 62 | 39.8±0.5 | 018.1±1.6 | 3.2 | — | — | — | — | — | — | — | — | — | — | — |
| L 41°42'N 66°36'W | 5 | 18 | 41 | — | — | — | 50.3±0.7 | 141.9±1.8 | 57.8±1.5 | 032.6±1.7 | 63.1±1.4 | -43.5±0.7 | 0.70 | 0.72 | 326.3±1.4 | 007.9±2.6 | 3.5 |
| M 40°51'N 68°48'W | 5 | 10 | 66 | — | — | — | 29.2±1.7 | 117.9±6.0 | 72.9±3.2 | 034.9±2.8 | 73.0±3.1 | -28.9±1.8 | 0.40 | 0.92 | 003.3±1.6 | 036.2±2.3 | 2.6 |
| | 4 | 51 | 66 | — | — | — | 21.9±1.7 | 124.3±2.0 | 59.6±1.9 | 030.0±0.8 | 59.6±2.0 | -21.9±1.7 | 0.37 | 0.93 | 358.1±0.7 | 029.3±0.7 | 2.8 |
| P 40°29'N 70°30'W | 3 | 61 | 71 | — | — | — | 10.8±0.1 | 063.2±3.1 | 9.8±0.4 | 341.7±4.3 | 11.2±0.0 | -9.4±0.5 | 0.84 | 0.54 | 060.9±2.9 | 038.1±6.2 | 2.5 |
| | 2 | 70 | 71 | 41.8±0.4 | 352.8±0.4 | 4.1 | 6.0±0.1 | 023.8±7.2 | 5.2±0.1 | 305.3±5.2 | 6.1±0.1 | -5.1±0.2 | 0.84 | 0.55 | 074.0±4.9 | 026.3±1.1 | 3.2 |

[1] Time Before High Water at Boston
* Eccentricity of tidal ellipse

## TABLE 2 - SEMIDIURNAL ($M_2$) TIDAL PARAMETERS FOR THE MID-ATLANTIC BIGHT

| Station lat/long fig 1 | No. of 29-day pieces | Meters below surface (m) | Mean water depth (m) | FOURIER COEFFICIENTS: PRESSURE Amp (mbar) | PRESSURE Phase-G (deg) | PRESSURE BHW[1] (hrs) | CURRENTS East Amp (cm/s) | CURRENTS East Phase-G (deg) | CURRENTS North Amp (cm/s) | CURRENTS North Phase-G (deg) | CURRENT ELLIPSE PARAMETERS: Umaj (cm/s) | Umin (cm/s) | Umin/Umaj | e* | Orient North=0° (deg) | Phase-G (deg) | AHW[2] (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MA 39°27'N 73°00'W | 2 | 58 | 59 | — | — | — | 5.4±0.2 | 317.2±4.5 | 6.0±1.5 | 248.1±0.7 | 7.4±1.3 | -3.4±0.1 | 0.46 | 0.89 | 319.1±8.9 | 225.5±8.5 | 4.0 |
| MB 38°44'N 73°38'W | 14 | 15 | 60 | — | — | — | 13.2±1.3 | 068.9±4.0 | 12.6±1.0 | 308.6±4.5 | 15.8±1.3 | -9.1±1.0 | 0.56 | 0.82 | 312.4±2.7 | 276.5±3.4 | 5.7 |
| | 2 | 45 | 60 | — | — | — | 12.6±1.0 | 057.5±5.2 | 12.5±1.0 | 295.8±2.5 | 15.5±1.0 | -8.7±1.1 | 0.56 | 0.83 | 314.8±0.0 | 266.5±3.9 | 5.4 |
| | 2 | 54 | 60 | — | — | — | 10.5±0.2 | 050.9±6.3 | 10.4±0.2 | 283.9±7.3 | 13.3±0.3 | -6.6±0.0 | 0.50 | 0.87 | 314.4±0.3 | 256.9±6.5 | 5.1 |
| | 3 | 59 | 60 | — | — | — | 5.6±1.0 | 053.1±4.9 | 5.8±0.9 | 282.7±5.4 | 7.3±1.3 | -3.4±0.4 | 0.47 | 0.88 | 316.4±1.9 | 258.9±3.8 | 5.1 |
| | 11 | 59 | 60 | 47.1±0.4 | 350.1±1.0 | 4.1 | — | — | — | — | — | — | — | — | — | — | — |
| MC 38°33'N 73°31'W | 1 | 79 | 80 | — | — | — | 4.9- | 40.9- | 5.5- | 270.9- | 6.7- | -3.1- | 0.46 | 0.89 | 320.6- | 250.2- | 4.8 |
| ME 39°57'N 72°36'W | 1 | 58 | 59 | — | — | — | 4.6- | 22.0- | 6.1- | 248.3- | 7.1- | -2.9- | 0.40 | 0.91 | 326.0- | 233.0- | 4.2 |
| | 1 | 59 | 60 | 48.6±0.1 | 347.5±0.4 | 4.2 | — | — | — | — | — | — | — | — | — | — | — |

[1] Time Before High Water at Boston
*Eccentricity of tidal ellipse
[2] Time After High Water at Boston

Table 3. Amplitudes and phases of semidiurnal tides ($M_2$) on the Continental Shelf: Nova Scotia to New Jersey

| Station | Longitude W. | Latitude N. | Amp (cm)* | Phase-G (degrees) | Source** |
|---|---|---|---|---|---|
| Nova Scotia Coast | | | | | |
| 1. Lockport | 65°07′ | 43°42′ | 69.8 | 359 | A |
| 2. Pinkey Point | 66°04′ | 43°43′ | 155.4 | 059 | A |
| 3. Seal Island | 66°00′ | 43°29′ | 120.4 | 052 | A |
| 4. Yarmouth | 66°07′ | 43°50′ | 163.2 | 063 | A |
| 5. Port Maitland | 66°09′ | 43°59′ | 185.1 | 066 | A |
| Continental Shelf at NE Channel | | | | | |
| 6. T22A | 65°30′ | 42°07′ | 45.8 | 364 | B |
| 7. T22B | 65°38′ | 42°03′ | 44.2 | 369 | B |
| 8. T23 | 67°45′ | 40°22′ | 40.7 | 356 | B |
| 9. T4 | 66°51′ | 40°44′ | 40.4 | 355 | B |
| 10. T3 | 65°48′ | 41°44′ | 39.6 | 362 | B |
| 11. T21 | 64°23′ | 42°37′ | 49.0 | 357 | B |
| 12. T1 | 63°13′ | 42°49′ | 48.2 | 350 | B |
| Gulf of Maine | | | | | |
| 13. Eastport, Maine | 66°59′ | 44°54′ | 261.4 | 070 | A |
| 14. Monhegan Island | 69°23′ | 43°40′ | 131.0 | 100 | C |
| 15. Cashes Ledge | 69°05′ | 43°11′ | 120.5 | 098 | C |
| 16. Cape Porpoise | 70°17′ | 43°13′ | 126.6 | 104 | C |
| 17. Boston, Mass. | 71°03′ | 42°21′ | 134.5 | 110 | D |

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*For stations A, D, K, E, B, P, ME, and MB, mbar pressure was converted to cm using 1 mb = 0.995 cm.

**A = Canadian Hydrographic Office; B = Garrett and Toulany (1979); C = Vermersch and others (1979); D = National Ocean Survey, U.S. National Oceanic and Atmospheric Administration (NOAA); E = this study; F = Redfield (1953); G = Beardsley and others (1977); H = Zetler and others (1975).

Table 3. Amplitudes and phases of semidiurnal tides ($M_2$) on the Continental Shelf: Nova Scotia to New Jersey (Cont.)

| Station | Longitude W. | Latitude N. | Amp (cm)* | Phase-G (degrees) | Source** |
|---|---|---|---|---|---|
| Georges Bank | | | | | |
| 18. A | 67°24′ | 40°51′ | 38.9 | 005 | E |
| 19. D | 67°47′ | 41°59′ | 75.8 | 093 | E |
| 20. K | 67°34′ | 41°03′ | 39.6 | 018 | E |
| 21. E | 65°51′ | 42°14′ | 45.- | 024 | E |
| 22. B | 69°00′ | 40°49′ | 26.- | 047 | E |
| Cape Cod Coast | | | | | |
| 23. Menemsha | 70°46′ | 41°20′ | 45.4 | 009 | E |
| 24. Nantucket | 70°06′ | 41°17′ | 43.0 | 136 | D |
| 25. Woods Hole | 70°40′ | 41°31′ | 21.4 | 035 | F |
| Transition Zone | | | | | |
| 26. P | 70°13′ | 40°29′ | 41.6 | 353 | E |
| Mid-Atlantic Bight | | | | | |
| 27. MIT/WHOI3 | 70°51′ | 40°18′ | 42.2 | 347 | G |
| 28. MESA 9 | 72°42′ | 39°45′ | 49.8 | 350 | G |
| 29. MESA 10 | 73°14′ | 40°00′ | 55.5 | 351 | G |
| 30. MESA 11 | 73°34′ | 40°08′ | 58.9 | 351 | G |
| 31. ME | 72°36′ | 39°57′ | 48.4 | 348 | E |
| 32. MB | 73°38′ | 38°44′ | 46.9 | 350 | E |
| New Jersey Coast | | | | | |
| 33. Sandy Hook | 74°01′ | 40°28′ | 65.5 | 004 | D |
| 34. Cape May | 74°58′ | 38°58′ | 70.8 | 023 | D |
| 35. Atlantic City | 74°25′ | 39°21′ | 58.3 | 350 | D |
| Ocean | | | | | |
| 36. Bermuda | 64°42′ | 32°22′ | 35.5 | 000 | H |

*For stations A, D, K, E, B, P, ME, and MB, mbar pressure was converted to cm using 1 mb = 0.995 cm.

**A = Canadian Hydrographic Office; B = Garrett and Toulany (1979); C = Vermersch and others (1979); D = National Ocean Survey, U.S. National Oceanic and Atmospheric Administration (NOAA); E = this study; F = Redfield (1953); G = Beardsley and others (1977); H = Zetler and others (1975).